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RESEARCH MEMORANDUM

EFFECT OF SPARK REPETITION RATE ON THE IGNITION LIMITS OF A SINGLE TUBULAR COMBUSTOR

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

EFFECT OF SPARK REPETITION RATE ON THE IGNITION LIMITS OF A SINGLE TUBULAR COMBUSTOR

By Hampton H. Foster

SUMMARY

An investigation was conducted to determine the effect of spark repetition rate on the altitude ignition limits of a single tubular (turbojet engine) combustor. The minimum combustor pressures at which ignition could be obtained were determined for a wide range of spark repetition rates. Data were obtained for two fuels of different volatility, two spark energy levels, and three air-flow rates in the range of altitude engine-windmilling conditions.

An increase in spark repetition rate from 3 to 140 sparks per second reduced the ignition limiting combustor-inlet air pressure from about 2 to 4 inches of mercury for air-flow rates of 1.87 and 2.80 pounds per second per square foot. For the highest air flow, 3.75 pounds per second per square foot, the ignition limiting pressure was reduced about 4 to 12 inches of mercury. The trend was similar for both the low- and high-volatility fuel and for two levels of ignition energy. Previously observed trends of lower ignition-pressure limits with decreased air-flow rates and increased fuel volatility were observed in this investigation.

INTRODUCTION

In an effort to improve the altitude starting characteristics of the turbojet engine, research is being conducted at the NACA Lewis laboratory on design and operating factors which may affect ignition limits of combustors. Several NACA investigations reported previously evaluated the influence of fuel volatility, spark plug location, and spark energy on ignition characteristics in both full-scale turbojet engines and single combustor installations (references 1 to 5). In addition to these factors still another variable, spark repetition rate, must be considered in the study of ignition limits. It is with this variable the present investigation is concerned.

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The results of one investigation (reference 6) indicate no effect of spark repetition rate for a range of 100 to 450 sparks per second with a homogenous fuel-air mixture in a static test chamber. For a nonuniform mixture of liquid fuel droplets, vaporized fuel, and air, however, an increase in spark repetition rate might be expected to (1) increase the probability of a spark occurring at the instant an inflammable mixture of fuel and air passes through the spark gap, and consequent formation of a small volume of burning mixture; (2) increase the number of small volumes of burning mixture which may combine and propagate throughout the combustor; or (3) increase the surface temperature of the electrode sufficiently to aid in the vaporization of the fuel. The ignition energy investigation of reference 4 indicates a slight effect of spark repetition rate on full-scale engine ignition limits. Preliminary data of reference 5, however, indicate a negligible effect of spark repetition rate on single combustor ignition limits.

The limited scope of the investigations of references 5 and 6 warrant further evaluation of the effect of spark repetition rate on the ignition limits of the single combustor. For this reason the investigation reported herein was conducted to obtain more conclusive evidence of the effect of spark repetition rate on ignition. This study was made in a single tubular combustor and altitude ignition limits were determined over a range of spark repetition rate from 3 to 140 sparks per second at two values of spark energy. The combustor-inlet air pressures which limited ignition, at a constant combustor-inlet air temperature, were determined for three air-flow rates in the range of engine altitude windmilling conditions and for two fuels, a MIL-F-5624 (JP-3) fuel and a modified MIL-F-5624 fuel having a reduced volatility (that is, a Reid vapor pressure of 1.0 lb/sq in.).

APPARATUS AND TEST CONDITIONS

Combustor

The single tubular (turbojet engine) combustor, ducting, and installation details are described in references 5 and 7. The instrumentation for indicating total pressures and temperatures at the inlet and exhaust of the combustor is described in reference 7. In order to minimize the effect of variation in fuel atomization, a variable-area nozzle (reference 8) was used in place of the standard simplex fuel nozzle. The variable-area fuel nozzle produced excellent spray characteristics at much lower fuel-flow rates than the simplex nozzle. The fuel supply and measuring system is described in reference 2.

Ignition System

A high-voltage, low-capacitance ignition system capable of a wide range of spark repetition rate (fig. 1) was used to investigate the altitude ignition limits of the single combustor. This system replaced the low-voltage, high-capacitance system used in the investigation of ignition energy requirements of the combustor (reference 5). It was found that with the high-voltage system there was less variation in the peak values of voltage at the various spark repetition rates.

The energy supplied to the discharge condenser is calculated as:

$$E = \frac{1}{2} CV^2 \text{ (reference 9)}$$

where

E energy, joules

C capacitance, farads

V voltage, volts (peak values)

The high spark repetition rate used in this investigation required an indirect method of measuring peak voltages. An oscilloscope was used to compared the voltage drop across the discharge condenser with the peak voltage of an oscillator, as shown in figure 1. The procedure was as follows: With the switch in position 1 (fig. 1), the spark repetition rate was established at the desired value by first setting the oscillator to the desired frequency and adjusting the multivibrator, which controls the spark repetition rate, so that a Lissajous figure indicating a 1:1 frequency ratio was obtained on the oscilloscope. The switch was then changed to position 2; the horizontal gain on the oscilloscope was adjusted so that only the vertical trace, representing condenser voltage drop, remained. The vertical gain was adjusted so that the trace was between two arbitrary fixed points on the screen. With the switch in position 3, the oscillator amplitude was adjusted so that the height of the new trace (oscillator voltage) was equal to that observed with the switch in position 2. The peak voltage was then read on a peak-to-peak Ballantine voltmeter. During step 3 it was necessary to have the spark in the "off" position to prevent interference from the ignition voltage.

A voltage divider of 1000 to 1 was used across the capacitor, necessitating a factor of 1000 on the peak reading voltmeter. Independent calibrations of the voltmeter and the oscilloscope indicated that these instruments were sufficiently accurate for this investigation.

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Despite probable energy losses in the discharge system, it is believed that the energy level at the spark gap remained constant for the range of spark repetition rates, inasmuch as the constants in the discharge circuit were not changed. High-speed photographs of the ignition spark (standard aircraft-type spark plug, 0.050 in. gap) at different energy levels and different spark repetition rates were obtained to substantiate, qualitatively, the constancy of the spark energy with repetition rate. Whereas differences could be observed, easily, between spark energies of 1.65, 2.45, and 4.5 joules, little or no difference was observed among pictures of the spark at a constant measured energy but at different spark repetition rates for a range from 3 to 140 sparks per second.

PROCEDURE

The controls and procedure in conducting this investigation were essentially the same as those described in reference 5, except that spark repetition rate was the controlled variable at two constant spark energy levels. The minimum combustor-inlet air pressure at which ignition could be obtained was determined for spark repetition rates of 3, 8, 16, 60, and 140 sparks per second. Data were obtained for three air-flow rates (1.87, 2.80, and 3.75 lb/(sec)(sq ft)) in the probable range of air flows at altitude engine-windmilling conditions (reference 1). The combustor-inlet air temperature was maintained at -10° F for all tests. Fuel was admitted to the combustor by opening the throttle slowly until ignition occurred, allowing a maximum time interval of about 30 seconds. The criterion for satisfactory ignition was that the flame fill the combustor and continue burning after the spark gap was de-energized. The fuel temperature was not controlled inasmuch as it had been found previously (reference 2) that the temperature of the fuel in the nozzle tip was essentially that of the combustor-inlet air temperature.

FUELS

Two fuels of current interest for use in turbojet engines were chosen for this ignition investigation.

(1) JP-3 fuel (MIL-F-5624, NACA fuel 51-38), a high volatility fuel with a Reid vapor pressure of 6.2 pounds per square inch.

(2) Modified JP-3 fuel (NACA fuel 49-246), obtained by removing volatile components from MIL-F-5624 to adjust the Reid vapor pressure to a nominal 1.0 pound per square inch (in this report, this modified fuel will be referred to as the "1-pound fuel").

Analyses of the two fuels are given in table I.

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RESULTS AND DISCUSSION

The effect of spark repetition rate on the minimum inlet-air pressure at which ignition occurred in the single tubular combustor is presented in figure 2. Data are presented for a high-volatility fuel and a low-volatility fuel (JP-3 and 1-lb fuel, respectively), three air-flow rates, and two values of spark energy.

It may be noted that the spark energy is indicated as arbitrary "spark energy units" rather than as the true energy in terms of joules. The actual value of spark energy at the spark gap is indeterminant because of large and unknown losses in the electrical system used, particularly in the (thyratron) 5C22 tube. However, as described in the section on APPARATUS AND TEST CONDITIONS, it is believed that the actual values of spark energy remained constant over the range of spark repetition rate investigated; and the effects of spark repetition rate indicated in figure 2 would then be valid. From a comparison of the ignition-pressure-limit data of figure 2 with data presented in reference 5 for the same combustor and operating conditions, an estimate of the actual spark energy can be made. Thus 4.5 spark energy units (figs. 2(a) and 3) represent about 0.45 joules and 9 spark energy units (fig. 2(b)), 0.9 joules.

The results of figure 2 indicate the expected trend of increased minimum ignition-pressure limit with increased air-flow rate and with decreased fuel volatility (reference 5). As the spark repetition rate was increased from 3 to 140 sparks per second, the combustor-inlet pressure-limiting ignition was reduced about 2 to 4 inches of mercury at an air-flow rate of 1.87 to 2.80 pounds per second per square foot. For a higher air-flow rate, 3.75 pounds per second per square foot, the corresponding reduction in inlet pressure varied from about 4 to 12 inches of mercury. The improvement in ignition characteristics resulting from an increase in spark repetition rate might be attributed to

(1) Increase in the probability of a spark occurring at the instant an inflammable mixture of fuel and air passes through the spark gap and consequent formation of a small volume of burning mixture

(2) Increase in the number of small volumes of burning mixture which may combine and propagate throughout the combustor

(3) Increase in spark-plug-electrode-surface temperature with a consequent increase in fuel vaporization rate

In order to determine the probable aid in fuel vaporization that might result from an increase in spark repetition rate, an attempt was made to measure the temperature of one spark plug electrode. A thermocouple was welded to the ground electrode (fig. 3) and connected to suitable instrumentation. The spark plug was installed in its regular position in the combustor, and the temperatures were measured (after stabilization) for the different inlet-air conditions (without burning). Figure 3 shows that, at the low spark repetition rates, there is little or no rise in electrode temperature above that of the combustor-inlet air temperature, whereas a substantial increase in electrode temperatu occurs at the higher sparking rates. The data indicate that some heat would be available at the surface of the electrodes to aid in fuel vaporization; consequently, an additional test was conducted to determine, at least qualitatively, the effect of this electrode temperature on ignition-pressure limits. A water-glycol mixture was used to cool a hollow (grounded) electrode (fig. 3) of the spark plug. Little or no effect of this cooling on combustor ignition limits was observed. No attempt was made, however, to cool both electrodes of the spark plug.

SUMMARY OF RESULTS

The following results were obtained from an investigation of the effects of spark repetition rate on the altitude ignition limits of a single tubular turbojet-engine combustor operated with two fuels of different volatility, two spark-energy levels, and three air-flow rates in the range of altitude engine-windmilling conditions:

1. For air-flow rates of 1.87 and 2.80 pounds per second per square foot, an increase in spark repetition rate from 3 to 140 sparks per second resulted in a reduction in the minimum combustor ignition-pressure limits of about 2 to 4 inches of mercury; for an air-flow rate of 3.75 pounds per second per square foot this reduction varied from about 4 to 12 inches of mercury.

2. Previously observed trends of lower ignition-pressure limits for a decrease in air-flow rates and an increase in fuel volatility were observed in this investigation.

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National Advisory Committee for Aeronautics
Cleveland, Ohio.

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TABLE I .- FUEL ANALYSIS

Fuel properties	MIL-F-5624 (JP-3 fuel)	MIL-F-5624 Modified (1-pound fuel)
	NACA fuel 51-38	NACA fuel 49-246
A.S.T.M. distillation D-86-46 (°F)		
Initial boiling point	113	210
Percent evaporated		
5	146	224
10	169	243
20	198	276
30	218	302
40	236	328
50	254	355
60	270	384
70	293	413
80	325	441
90	388	478
Final boiling point	473	560
Residue (percent)	1.0	1.0
Loss (percent)	1.2	1.0
Reid vapor pressure (lb/sq in.)	6.2	1.0
Hydrogen-carbon ratio	0.172	0.157
Heat of combustion (Btu/lb)	18.763	18.560
Specific gravity	0.742	0.803
Freezing point (°F)	< -76	< -76

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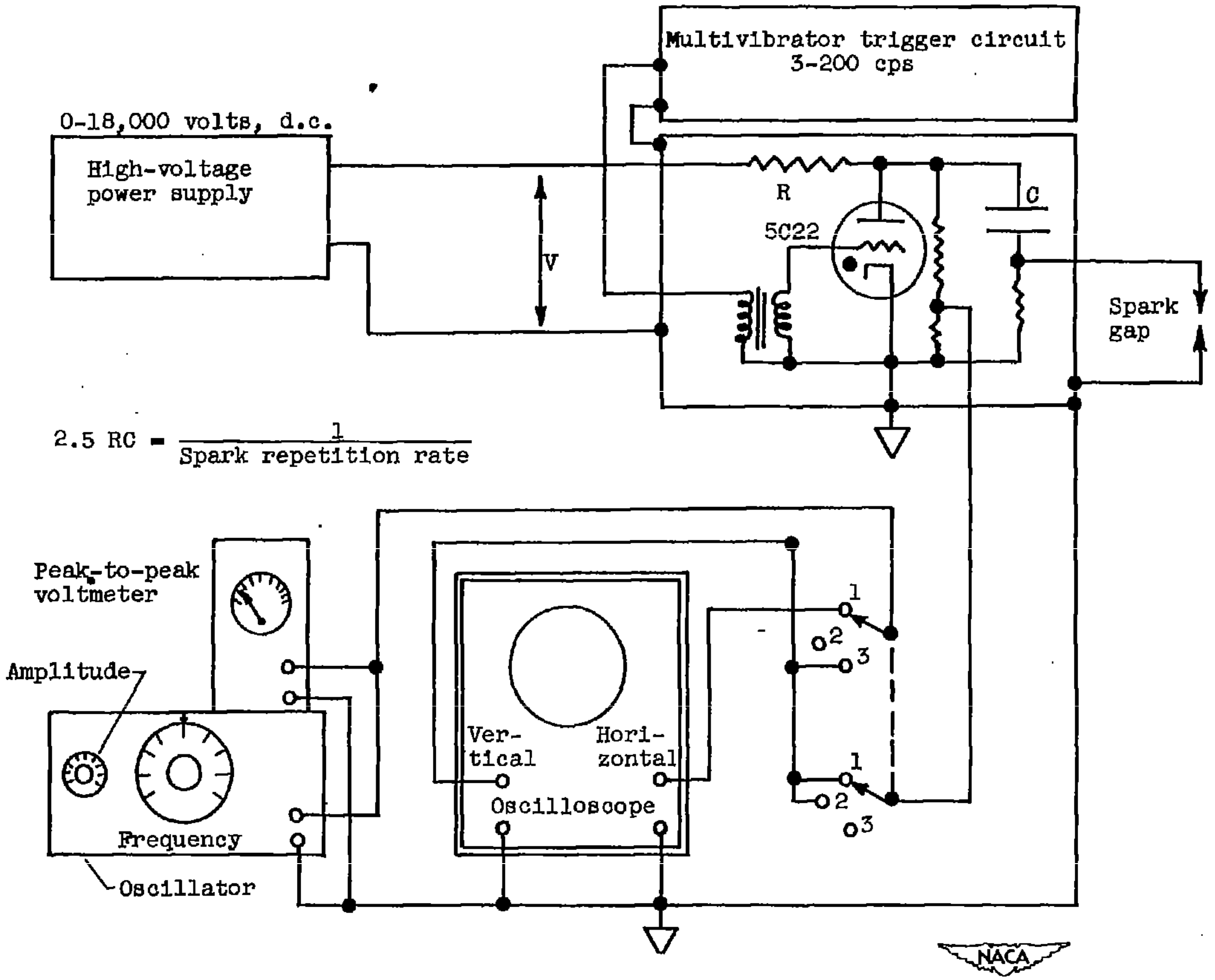

Figure 1. - Block diagram of high-energy ignition source and controls.

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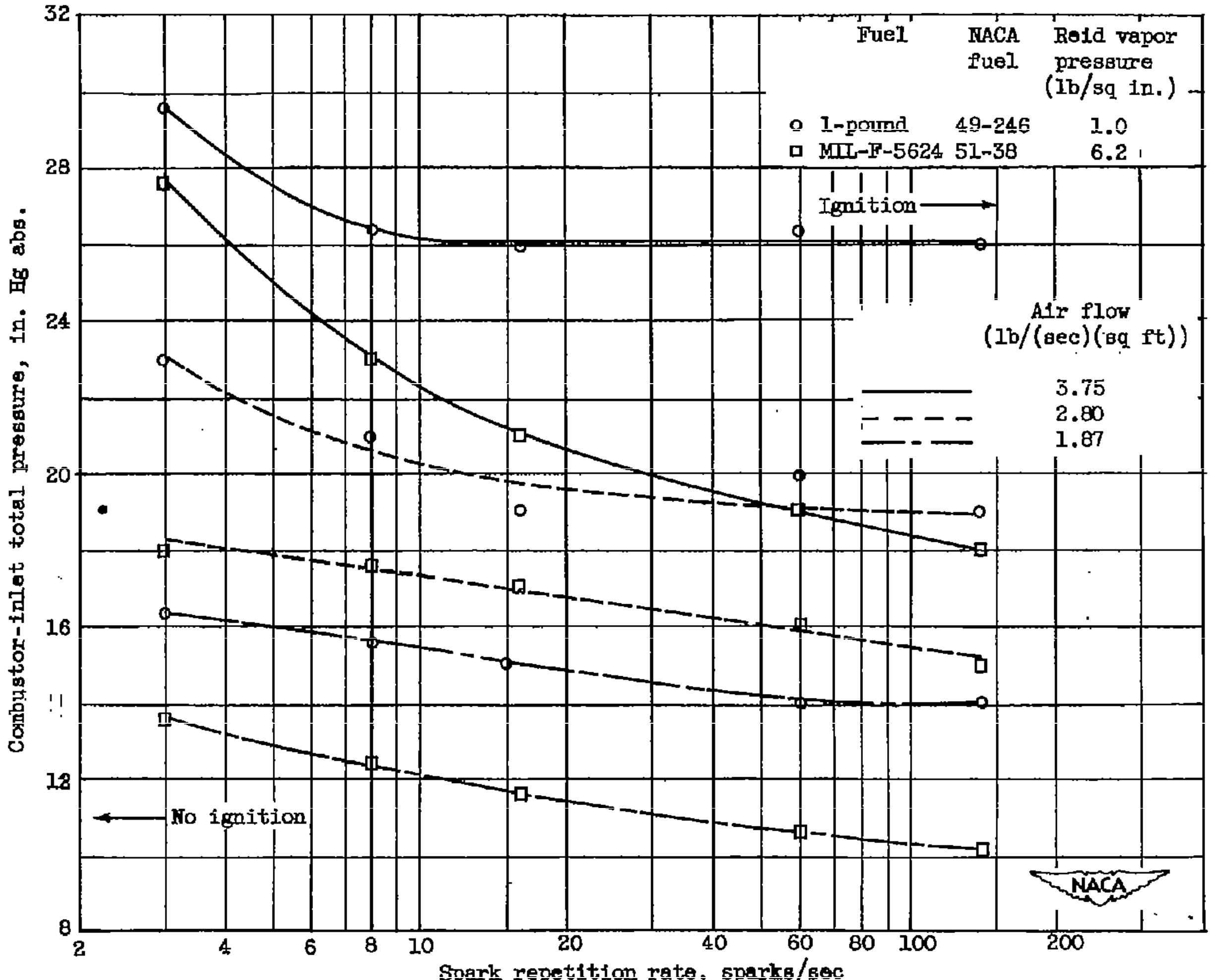

(a) 4.5 spark energy units.

Figure 2. - Effect of spark repetition rate on the minimum combustor-inlet pressure for ignition at several air-flow rates and two fuels of different volatility.

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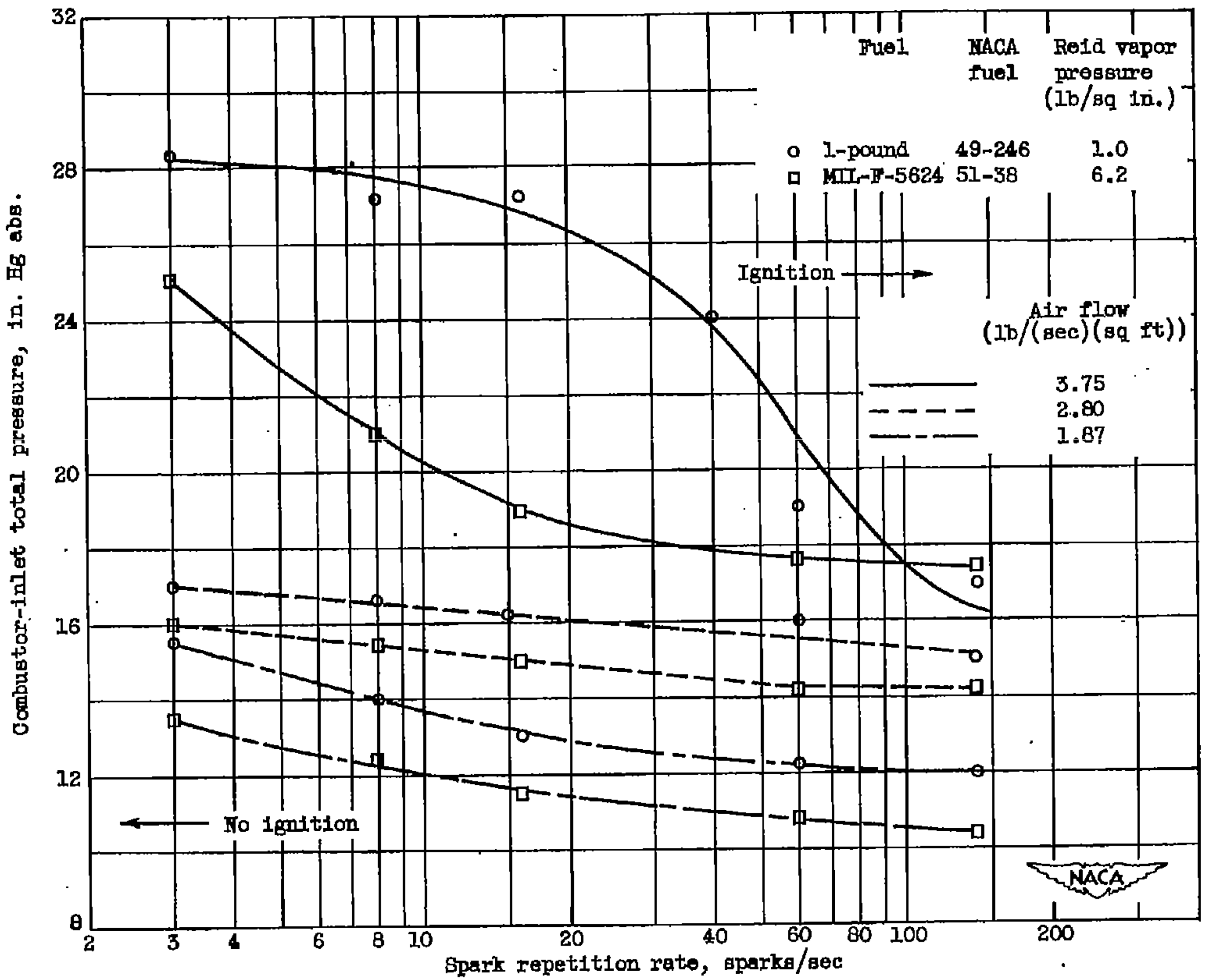

(b) 9 spark energy units.

Figure 2. - Concluded. Effect of spark repetition rate on the minimum combustor-inlet pressure for ignition at several air-flow rates and two fuels of different volatility.

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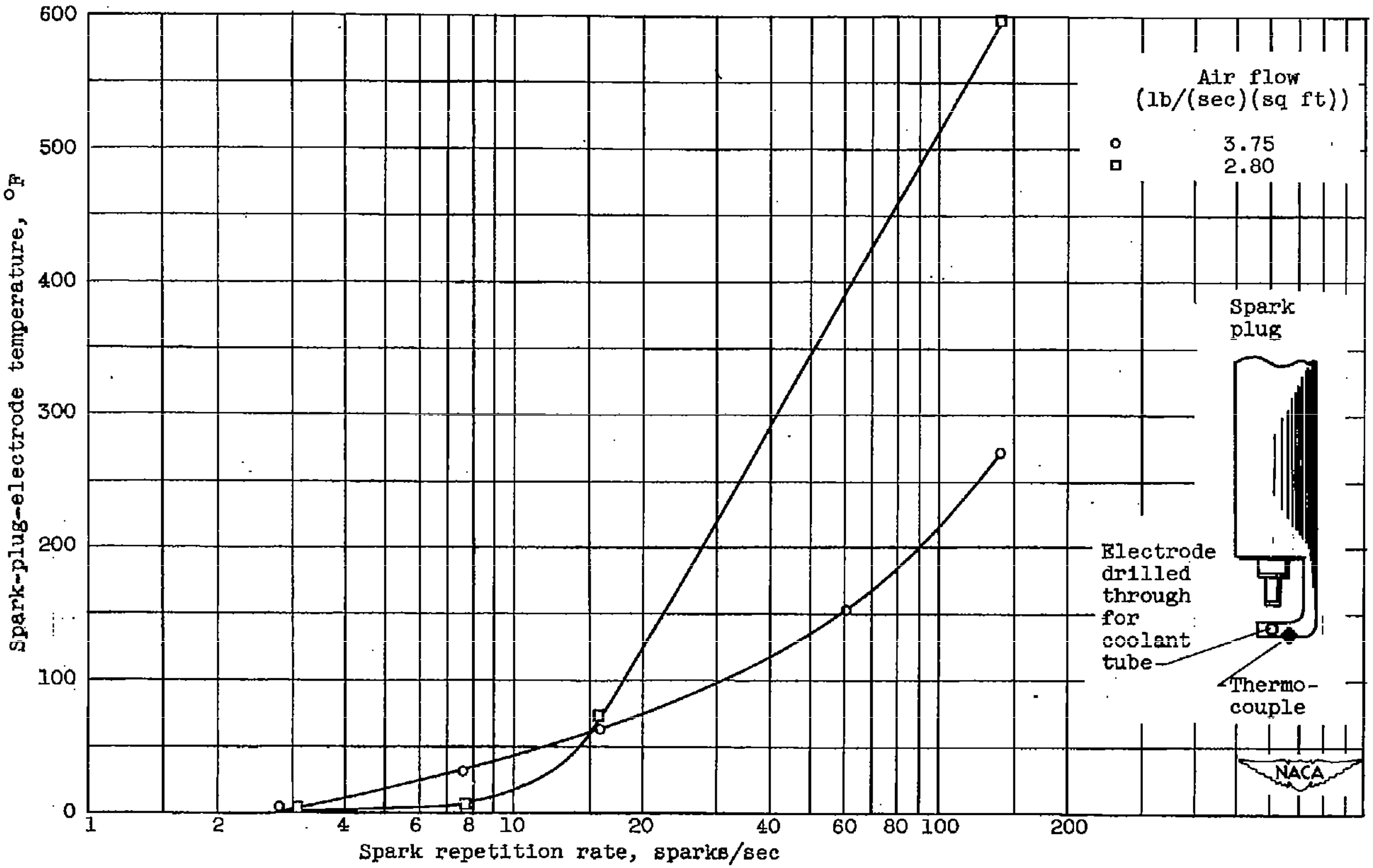

Figure 3. - Effect of spark repetition rate on the spark-plug-electrode temperature at different air-flow rates. Spark energy units, 4.5; air temperature, 0° F.